EVALUATION SYSTEM FOR PRACTICAL AC RESISTANCE TO THE 6SEGMENTED ENAMEL COATED POWER CABLE

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Abstract: For the enamel coated cable to increase the current carrying capacity, it is required to evaluate the capability of manufactured cable with ac resistance for real resistance component. But it is very hard to measure the ac resistance for the enamel conductor because of relatively big reactance. This paper presents the calibration method, how to terminate, data gathering, eliminating harmonics, signal line, set up and optimized current magnitude for test object. All those performance to get a precise ac resistance results were applied to the real energy systems for New Zealand project.

1 INTRODUCTION

In past, the DC resistance was important factor to evaluate a cable's characteristic. But, recently the cable conductor is various and some insulating wires are tried to adapt to cable conductor for reduction of not resistance but impedance.

The enamel coated cable was designed and manufactured a pilot sample before several years. But it was difficult to measure an AC resistance although knowing theory of the general measuring method through CIGRE and thesis. The difference of measuring results was large according to measuring time and space, connecting method and etc. And first of all, the error between calculation value and measured value of reference conductor for calibration was so large.

Many trial and errors were continuous for the development the measuring system. But, finally the procedure and standards for measurement of the AC resistance was defined. The initial design of the enamel coated cable was proved to poor performance and the design of the cable improved and second design of the cable was verified good performance of AC resistance. The enamel coated cable developed by this process successfully adapt to New Zealand project.

This paper introduces some factors and measuring system based on the experience and experiments.

2 GENERAL INSTRUCTIONS

2.1 Measuring system model

CIGRE working group B1.03 suggest several model for measurement of AC resistance. Among them, test methods using the sheath as the return conductor and superposition of a compensating voltage are selected by test model because these test model is concerned a low level of difficulty compared with others.

After many experiments, the test method of superposition of a compensating voltage is more accuracy than method using the sheath in our experiment. The test method using the sheath as the return conductor has an advantage hardware because of minimizing of the mutual inductance. But, the ratio responding of resulting error versus input noise is so sensitive. By contrast of that, the gain of error is insensitive in measuring system of superposition of a compensating voltage.

2.2 Environment

The measurement of AC resistance had been progressed at shield room, HV laboratory having a good performance of ground and vacant lot. The measurement of the AC resistance was affected from potential noise from ground and mutual inductance with any metal structure or material.

2.3 Signal line

Rounding the signal line at sample is valid to eliminate the effect of magnetic field on the signal line. And because of the horizontal magnetic field from cable conductor having a pitch, two rounding directions are required.

2.4 Termination of sample

Flow of the current to the cable conductor is different in each type of terminating method. The compressing method by copper terminal shows a good performance.

2.5 Current

Three type of the current source were adapted to measure an AC resistance. The current transformer using an induced current is useful to eliminate any noise and harmonics.

2.6 Calibration

To minimize an error from rising a temperature, the reference conductor for calibration is used in loop of the system.

3 DETAILED INSTRUCTIONS

3.1 Measuring system model

Two test models among the CIGRE were tested and insensitive test model from any noise and error was superposition of a compensating voltage.

Test method using the sheath as the return conductor: It was tried to measure an AC resistance of the cable by this measuring method(Fig 1). Initially, it was guessed that this test method is so comfortable and has a high reliability. Because it was no need any special device and the system eliminate the mutual inductance by a coaxial effect.

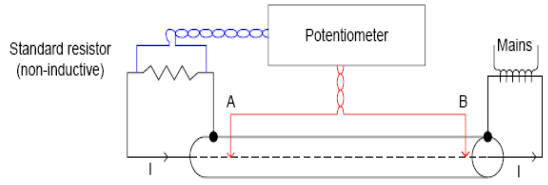

Fig 1. Measuring circuit using the sheath as the return conductor indicated in CIGRE.

Practically, the system was made like Fig 2 and experimented many times. But, the measuring system had shown a large difference between each result that had measured at different time.

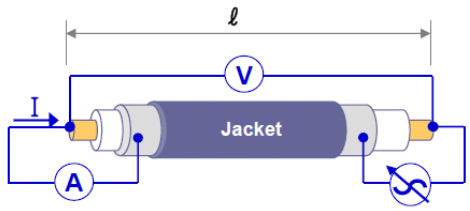

Fig 2. Practically adapted measuring system

This test method have two problem like below

1) Sensitive gain of the error: The results of the test take from calculation by (1).

$$Rac = \frac{V_d \times \cos\theta}{I \times \ell} \quad \left[\Omega/km\right] \qquad (1)$$

- Vd : Potential between measured sample
- I : Current of the sample
- θ : Phase between I and Vd
- ℓ : Length of the measured sample

In this, the phase between current and voltage generally measured 80~83°. This value is reasonable aspect ratio of inductance and resistance of cable. But small error of the phase takes large error to result because of Cosine function.

2) Difficulty of making an ideal coaxial effect: The contact point in CIGRE is a surface of the conductor located inside of the outer metallic sheath. It means that the measuring point of potential is affected of effect of coaxial to minimize a mutual inductance. But practically, the end of the conductor should be open from metallic sheath and the magnetic field is not cancelled at end of the cable. So, some metallic shield should be made in end of the cable but, it is also inducing a distortion that is different with each shape and sort of the metal.

Test method of superposition of a compensating voltage: This test method have an advantage reducing a phase between current and voltage compared with the test method mentioned previously. This test method use an induced voltage from current flowing at the test loop. The measured phase between current and voltage adjust to 0° and the magnitude of current and voltage also are varied depending on the phase. Because of the change of the measuring factor by hardware, the magnitude of an error occurring by Cosine function could be reduced compared with the test method using the sheath as the return conductor. Because the differential coefficient of the Cosine function should be almost zero near of the 0°. This test method could be solution of the sensitive gain of the error.

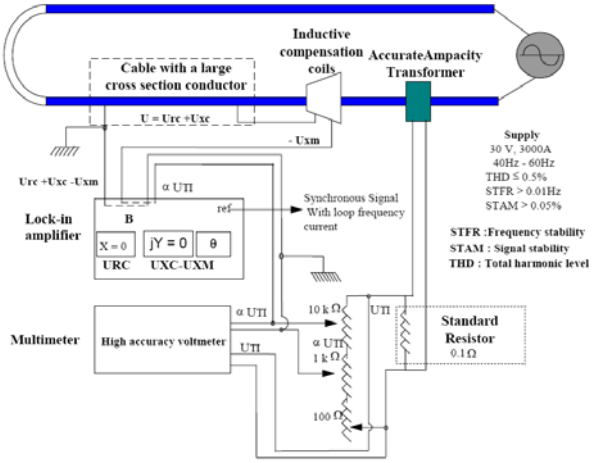

Fig 3. Measuring system of superposition of a compensating voltage indicated in CIGRE.

Simply the test circuit of the test method is comprised like Fig 4.

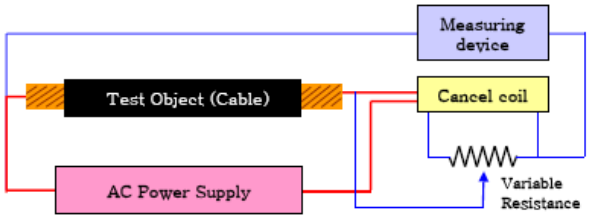

Fig 4. Practically adapted measuring system

The inductive compensation coil(cancel coil) is meaning the inductive compensating coils of Fig 3. The induced voltage of the cancel coil is overlapped to measured voltage between each end of the test sample but, the magnitude reflecting to overlapped voltage is controlled by variable resistance. In this principle, the reactance factor of measured impedance should be compensated. On the other hand, the magnetic field from current couldn't be offset. Because of this, it is required a lot of effort to remove any noise, harmonics, mutual reactance. Nevertheless this test method is better than the test method of using a sheath as a return conductor in terms of that the error is possible to control.

3.2 Environment

The measurement of AC resistance had been progressed at shield room, HV laboratory having a good performance of ground and vacant lot. The AC resistance was known to be sensitive to noise. So, initial measurement was progressed in shield room to protect from any noise. But, the results were disappointed. The results measured in each time had large difference with each other. The measurement in HV laboratory also failed. But, the measurement in vacant area was satisfied. The reason of the error is analyzed from noise and mutual inductance from ground and metal structure. Well known, the shield room is made by metal wall and floor and have a good performance of ground system. Also the HV laboratory has a good performance of ground system having an earthing resistance below 1Ω. Furthermore heating cycle test is often going on in the HV laboratory. In these facts, the measuring error of the AC resistance is related with the noise and mutual inductance from ground system and metal structure. Of course, this is clearly correlated with the measuring system that couldn't offset the magnetic field of current from the sample.

The vacant lot is optimum place to avoid any noise and mutual inductance from any metal. Even the iron bar could be operated by noise and mutual inductance.

Place	Target value (mΩ)	Measured value (mΩ)
Shield Room	8.92	8.5~13.5
HV laboratory	8.92	11.1~18.4
Vacant lot	8.92	8.90 (stadard deviation:0.0026)

Table 1. Measured value in each places

3.3 Signal line

As mentioned earlier, the test method of the superposition of a compensating voltage could be offset the magnetic field. So, the signal line to measure a potential of sample is affected from magnetic field that is occurred from current. So, induced voltage is adapted to signal line and the measured voltage have a distortion that is overlapped an induced voltage to measuring voltage.

Magnetic field of circumferential direction: This magnetic field is occurred from current of axis of the sample. To eliminate an induced voltage from this magnetic field, the signal line should be rounded. In this method, the magnetic field of one side could be offset from magnetic field of other side.

Magnetic field to axis of the sample: The conductor of the HV cable generally has a pitch that comprised wire is twisted regularly. Because of this, the current also flow by rotating through the conductor. The magnetic field to axis of the sample occurs by this principle. And this magnetic field also affect to signal line and lead to distortion of the results.

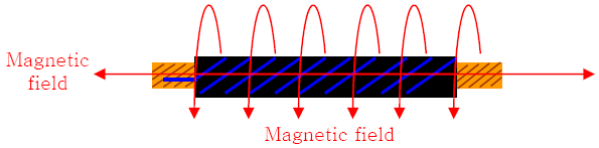

Fig 5. Magnetic field during applying a current

To solve of this problem, bidirectional rounding signal lines are needed like Fig 6. Induced voltage in each rotary direction could be offset by common at each end of the sample.

Fig 6. Common of bidirectional signal line

Practically, the measured result was different like table 2.

Signal line	Measured value(mΩ)
Clockwise	7.82
Counterclockwise	8.36
Common each direction	8.09

Table 2. Results in each direction

The significant fact of this test result is that result of the common with each direction is same with average of each results of direction.

3.4 Terminal method of sample

The contact resistance is important fact at measurement of resistance. So, there were a lot of efforts to reduce the affect of the contact resistance in even dc resistance. In this measurement of AC resistance, it is tried to reduce the contact resistance by experiment. Simply three terminal methods are introduced in this page.

Soldering method: This terminal method induces error from contact resistance. It is analyzed that lead between wires of conductor occurs to raise the resistance. And this test method has a large deviation in each working.

Fig 7. Soldering method

Wiring method: The purpose of this method is for supply of same current in each wire. Every wires solder in each electric wire and the wires connect to plate. Also this method has a critical problem that the current is divided in each skin effect before the measuring point of the potential.

Fig 8. Wiring method

The current of each electric wire was different like table 3. It means that the input current to conductor is not valid to measure an AC resistance because of affect of the electric wires to skin effect.

125	84	126	94	124	82	76	121	114	76	74	95	81	100
128	122	101	121	128	126	85	111	94	112	109	117	117	100
106	123	109	121	123	110	116	115	95	116	102	110	110	
124	126	79	113	125	108	119	71	119	116	108	110	118	
126	122	96	86	119	95	113							Unit : mA

Table 3. Current distribution of in each electric wires

Compression method: This method is simple but most effective to minimize the contact resistance. But, the compressive strength is related with the contact resistance so, optimizing compressing strength should be standardized. And the material of the binding or terminal also affect to the contact resistance and AC resistance. Especially, material having a magnetic characteristic induces some distortion to the results because of the contact of special induced voltage to conductor.

Fig 9. Compression method

3.5 Current

The source and magnitude of current is also affecting to error. Some current sources include some noise or harmonics and this noise and harmonics result in some error of measured value. And the magnitude of the current is related with error induced by mutual inductance and temperature.

Source of the current: Because of the affect to the current directly, the source of the current is so important. Generally the factory has many manufacturing line. So, the quality of the power is not good and has some noise, harmonic and others. Normally those noise factors are not harmful for operational machine but it could be a big meaning in a measuring device with milivolt unit. So, the system of AC resistance is so sensitive to the quality of the power.

Some types of the source were experimented. Power supply to supply current directly is easy to reveal from noise. Sometimes noise and harmonics are used to mixing to the power and the noise and harmonics are reflected to results like Fig 10.

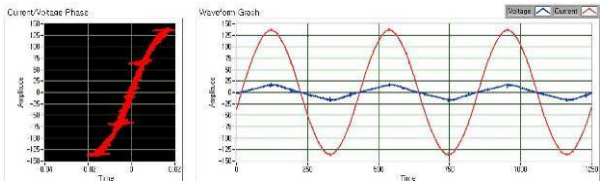

Fig 10. Graph mixed a harmonics and noise

To eliminate the harmonics and noise, noise filter was inserted to the current supply but, there was no effect. On the other hand, instead of direct current supply, current transformer using an induced current doesn't occur a noise and harmonics in any case. The reason of the filtering is analyzed that 2nd inducing voltage makes more complete sine wave.

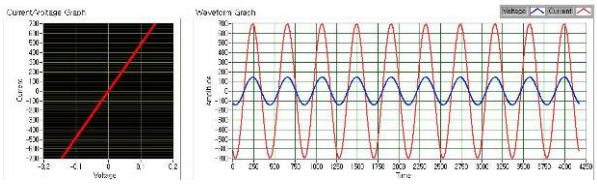

Fig 11. Graph of the normal state not mixed a harmonics and noise

The total harmonic distortion is below 0.2% and it is satisfied Max. 0.5% stated at the recommendation of the CIGRE.

Magnitude of the current: The error rate between the calculating value and measured value is decreasing according to increasing the current like Fig 12. And the reason of the decreasing of the error is caused from relatively small resistance compared with any noise. But, the differential value is decreasing according to increasing the current. And after 300A, the change of the ratio is insignificant. In the other hand, the decreasing time of the current is bigger than increasing time of the current. This is caused from heating of the conductor and other composite factor. The temperature of the test loop caused the error. So, it is important to standardize the optimum current from experiments.

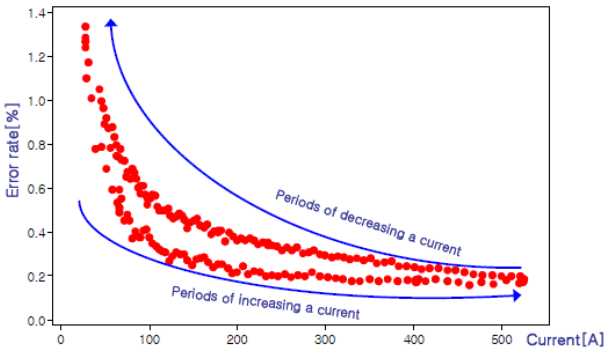

Fig 12. Error rate according to the magnitude of the current

3.6 Calibration

For a calibration to the measuring system, the bare conduct is needed by reference resistor. Contrary to cable conductor, bare conductors are easy to calculate the ideal resistance. So, it is appropriate to reference conductor. The 18Ø, 30Ø, 40Ø conductors was used to experiment to reference conductor. These conductors were made by electrical copper. But, the 40Ø conductor is shorter than others because of difficulty of manufacturing. The results of error ratio on each bare conductor are like Table 4. Accurately the deviation of the results on 40 Ø bare conductors is large than 18Ø, 30Ø bare conductor. It is analyzed that the sensitive gain of the 40Ø bare conductor is bigger than others. And this is induced from shorter length.

Conductor	Length	Error ratio compared with calculation
18Φ	11m	+1.02%
30Φ	11m	+0.20%
40Φ	5.5m	−2.67%

Table 4. Error ratio on each bare conductor

The 30Ø bare conductor was concerned relatively to be accurate. The conductor of the selected reference conductor formed in the circuit of the loop. By doing so, the calibration before the test on the sample could be performed rapidly. From this, the error from heating could be minimized.

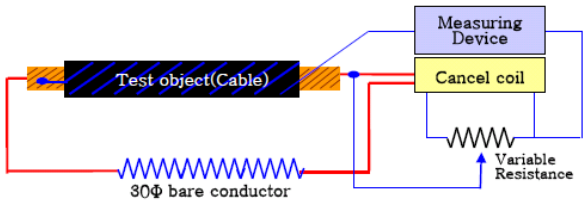

Fig 13. Schematic of measuring system added the reference conductor

3.7 Composition of the system

The composition of the measuring system for AC resistance is like Fig 14. The main technique for the system is same as mentioned earlier.

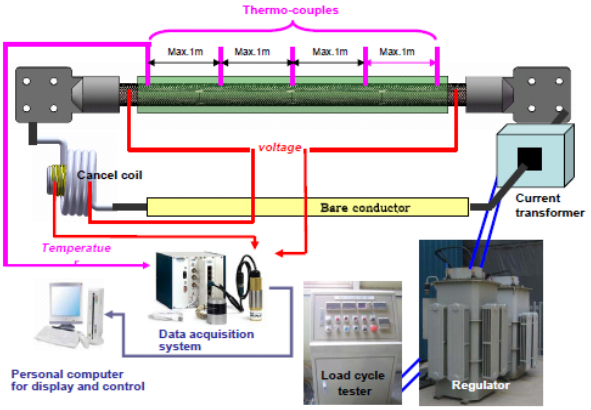

Fig 14. Schematic of the measuring system for AC resistance

And the display and control part is same with Fig 15. By some calculation from the program, the AC resistance and skin effect is automatically displayed.

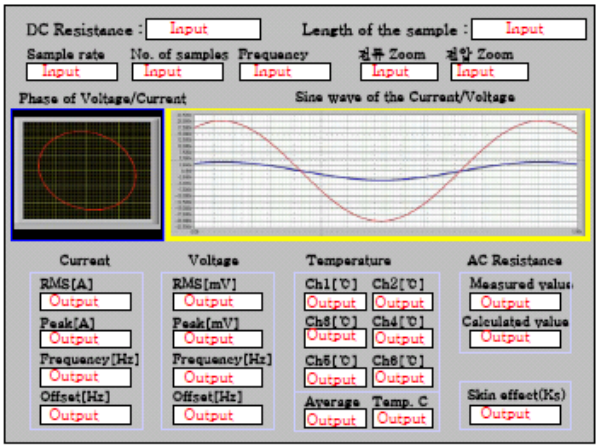

Fig 15. Control display for the measuring system

4 CONCLUSION

Through this paper, some factors considered by important condition and environment were mentioned. Although not mentioned in this paper, some factors are also important that are length of the sample, distance from current terminal to location of voltage sensor, sampling from gathering signal, and others. Most important thing to measure the AC resistance is that the AC resistance is so sensitive from any noise and mutual inductance, and harmonics, and etc. The operator has to concern all of the possibility and then all of the optimal conditions should be standardize.

The project to establish the measuring system takes so many times. And because of the success of this project, the enamel coated cable having a good performance could be developed. And the New Zealand project is progressing from last year.

5 REFERENCES

[1] CIGRE Working Group B1.03 (June. 2005)